CHAPTER 10

ALTERNATE TYPES OF RETAINING WALLS

Section I. Introduction

10-1. Classes of Retaining Walls. The four basic classes of retaining walls are gravity, cantilever, anchored, and mechanically stabilized backfill. Gravity walls rely on the weight of the wall system to resist overturning. The cantilever wall is fully reinforced to resist applied moments and shears. Anchored walls resist lateral forces primarily by the use of tieback anchors. Mechanically stabilized backfill involves the inclusion of reinforcement in the soil to form a coherent mass (Godfrey 1984, Mitchell, Villet, and DiMillio 1984, and Jones 1985).

10-2. Alternate Types of Retaining Walls. As discussed previously in Chapter 2, the most common types of retaining walls are gravity and cantilever walls constructed of cast-in-place concrete. Recently, however, a number of wall systems utilizing mechanically stabilized backfill as well as new types of gravity walls have been developed (Godfrey 1984). This chapter briefly describes mechanically stabilized backfill systems and precast concrete modular systems. The mention of any specific wall system does not constitute an endorsement or approval. Numerous wall systems are available and should be considered when appropriate. This manual does not attempt to provide complete design and/or construction procedures for the types of walls described in this chapter. Normally, design and construction procedures are provided by the manufacturer. However, the manufacturer normally provides only part of the design. The design engineer must assure the overall adequacy of the design.

Section II. Mechanically Stabilized Backfill Systems

10-3. General Background. Reinforced soil is a construction material composed primarily of soil with a performance that has been improved by the introduction of small quantities of other materials. These materials are in the form of strips, grids, sheets, rods, or fibers which strengthen the soil to resist tensile forces that soil alone is unable to withstand (Al-Hussani and Perry 1976 and Collin 1986).

10-4. Available Systems. Several mechanically stabilized backfill systems are available for retaining walls (Mitchell and Villet 1986).

a. Basic Components. Mechanically stabilized backfill systems have three major components: reinforcements, soil backfill, and facing elements. Both metallic and nonmetallic (geotextile, plastic) materials have been used for reinforcement. Granular material is normally used for soil backfill to meet stress transfer, durability, and drainage requirements. Facing elements are used to retain backfill material at the face of the wall, to prevent erosion of steep faces, and for aesthetic reasons. The facings are designed to resist only small horizontal earth pressures. Facing materials commonly used include precast concrete panels, prefabricated metal sheets and plates, welded wire mesh, inclusion of intermediate reinforcements between main reinforcement layers at the face, and seeding of the exposed soil.

b. Basic Mechanisms and Behavior. The two primary mechanisms of stress transfer between the reinforcement and soil are friction between plane contact surface areas and passive soil-bearing resistance on reinforcement surfaces oriented transverse to the direction of movement. Strip, sheet, and rod reinforcements transfer stresses to the soil by friction, while grid reinforcements transfer stresses primarily by passive resistance. Geogrid reinforcements develop both frictional and passive soil resistance.

c. Strip Reinforcement. With strip reinforcement, a mechanically stabilized backfill is created by placing strips in horizontal planes between successive lifts of soil backfill. Reinforced earth, shown schematically in Figure 10-1, is a strip reinforcement system.

d. Grid Reinforcement. Grid reinforcement systems are formed by placing metallic or polymeric tensile resistant elements in horizontal planes in the soil backfill. Retaining walls using bar-mesh reinforcement have been constructed by the California Department of Transportation, Hilfiker Retaining Walls; VSL Corporation, and the Georgia State Highway Department (see Figures 10-2 and 10-3). Grid reinforcements are also made of polymer materials, such as Tensar Geogrid (see Figure 10-4).

10-5. Advantages and Disadvantages. The advantages and disadvantages of mechanically stabilized backfill systems are outlined below (Mitchell and Villet 1986).

a. Advantages.

(1) Mechanically stabilized backfill systems are economical when compared to conventional retaining walls.

(2) Construction of mechanically stabilized backfill systems usually is easy and rapid. It does not require skilled labor or specialized equipment. Many of the components are prefabricated allowing relatively quick construction.

(3) Regardless of the height or length of the wall, the structure remains stable during construction.

(4) When compared to conventional retaining walls, mechanically stabilized backfill systems are relatively flexible and can tolerate large lateral deformations and large differential vertical settlements (when this is anticipated, vertical sliding joints can be installed at intervals to compensate for movement). The flexibility of mechanically stabilized backfill systems allows the use of a lower factor of safety for bearing capacity design than conventional more rigid structures.

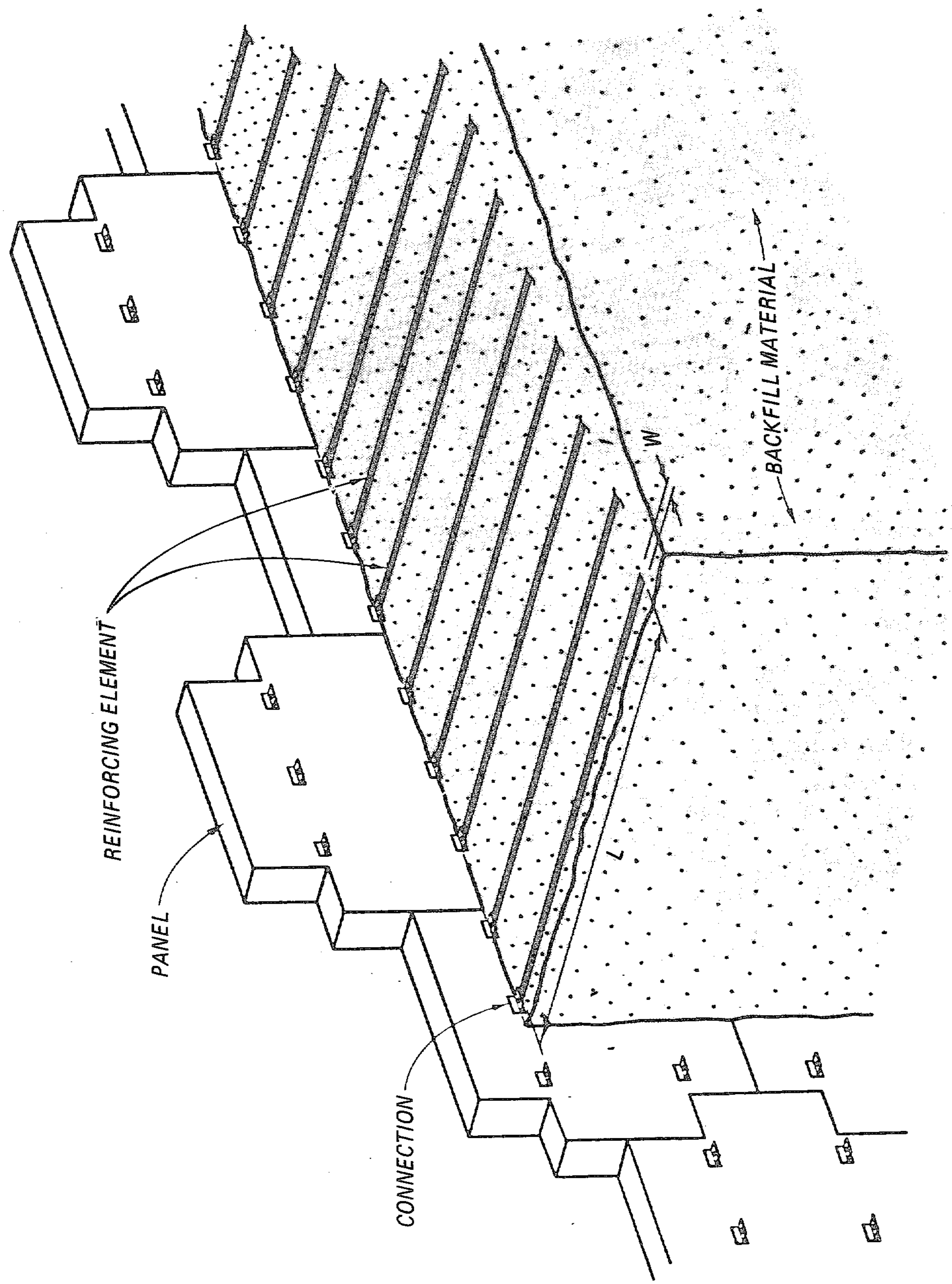

Figure 10-1. Schematic diagram of reinforced earth retaining wall

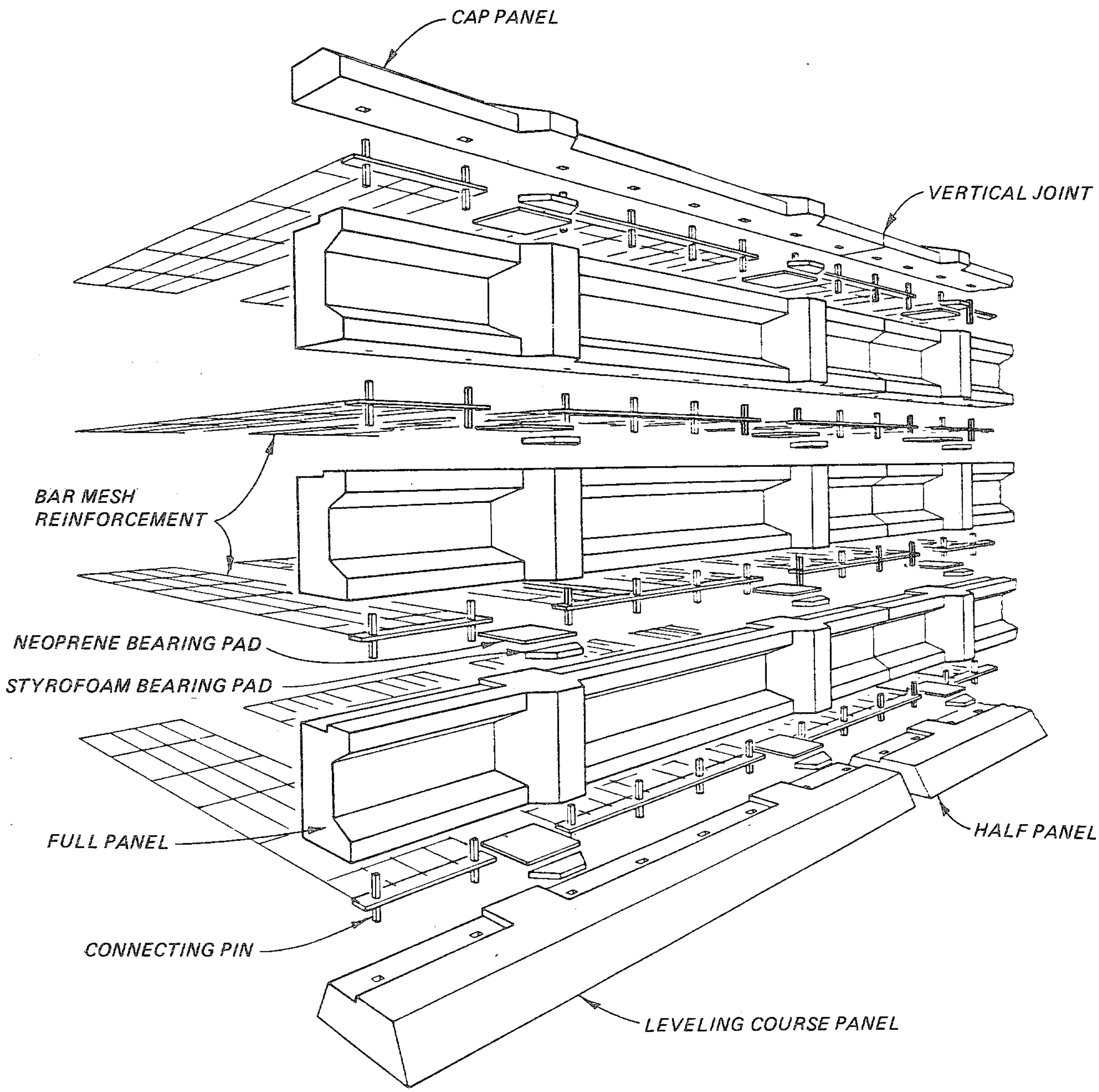

Figure 10-2. Schematic diagram of reinforced soil embankment retaining wall (after Hilfiker Company)

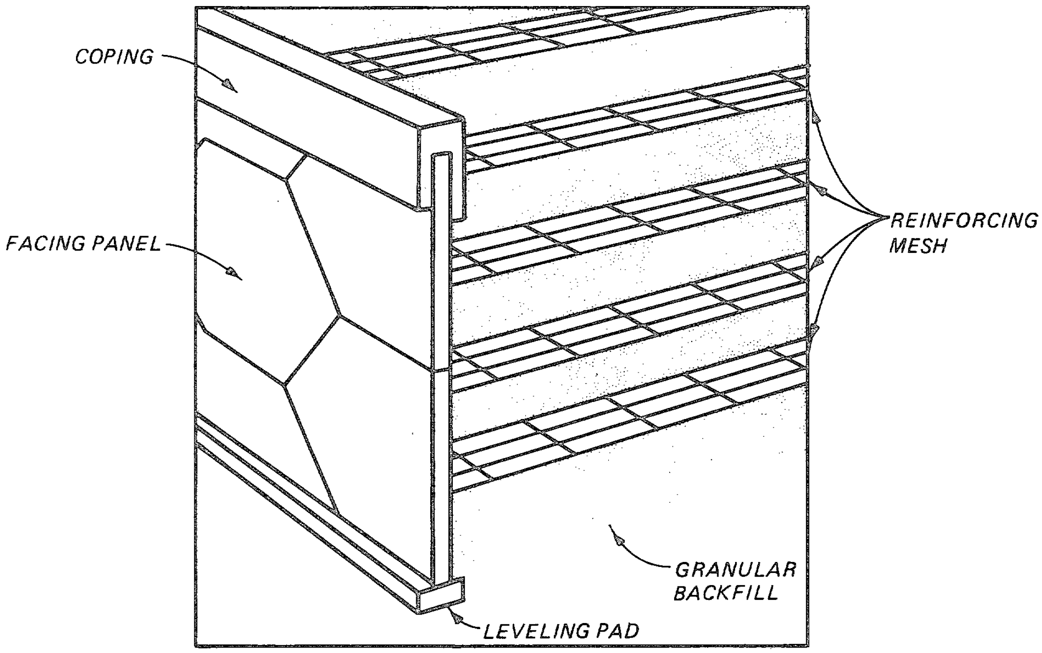

Figure 10-3. VSL retained earth retaining wall (adapted from VSL Corporation 1984)

(5) Mechanically stabilized backfill systems are potentially better suited for earthquake loading than conventional retaining walls because of the flexibility and inherent energy absorption capacity of the coherent earth mass. In designing mechanically stabilized backfill systems for earthquake regions, provision should be made for slippage of reinforcement elements rather than tension failure of the elements, resulting in a ductile structure (McKittrick 1979).

(6) Mechanically stabilized backfill systems, because of their flexibility and mass, are capable of withstanding dynamic loads imposed by wheel loads, wave action, and impact of small boats.

(7) Polymeric reinforcements are stable under chemical and biological conditions normally occurring in soils.

(8) Since facing elements play only a secondary structural role, a greater flexibility is available to meet aesthetic requirements than for conventional retaining walls. Facing arrangements range from concrete panels of

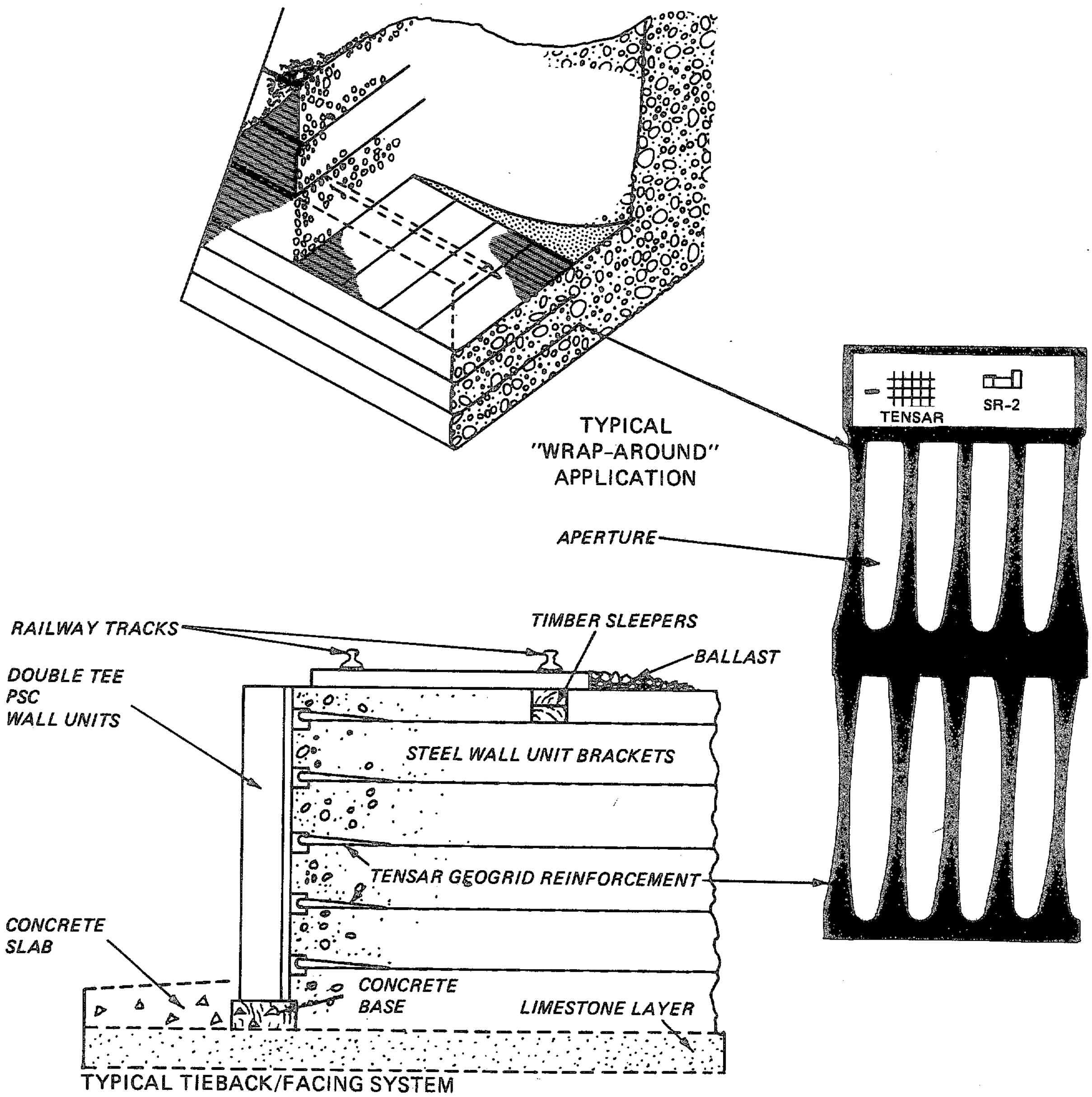

Figure 10-4. Tensar geogrid retaining wall (adapted from Tensar Corporation 1984)

various shapes, textures, and colors to provision of vegetation at the exposed face of the soil.

b. Disadvantages.

(1) Corrosion of metallic reinforcement occurs and must be assessed on a project basis by determining the potential aggressiveness of the soil. Special coatings such as galvanized zinc and resin-bonded epoxy are used with a sacrificial thickness of steel added in the design to give the required service life.

(2) Although polymeric reinforcement is a robust material, some allowance must be made for decrease in strength due to abrasion during construction. This will vary with the type of reinforcement material.

(3) Different polymers have different creep characteristics. Allowable loads in the grid should be selected based on allowable deformations, as well as the results of creep tests (10,000 hour). See McGown et al., 1985, for load-strain-time behavior of Tensor geogrids.

(4) The construction of mechanically stabilized embankments in cut regions requires a wider excavation than conventional retaining walls.

(5) Excavation behind the mechanically stabilized wall is restricted.

10-6. Cost Considerations. Mechanically stabilized backfill systems are particularly economical when compared to conventional retaining walls for earth fill situations where the retaining wall has a total surface area greater than 2,000 sq ft, average wall height greater than 10 feet, or where a rigid conventional wall requires a deep foundation for support. Precast concrete modular systems are cost-effective compared to conventional retaining walls for cut sides of excavations where the wall surface area is greater than 500 sq ft and average wall height is greater than 8 feet. The cost effectiveness of mechanically stabilized backfill systems will probably be reduced by high-cost backfill, complicated horizontal alignment, or the necessity of providing temporary excavation support systems during construction. For excavated side slopes, mechanically stabilized backfill systems can be constructed for 30 to 50 percent less than conventional retaining walls. However, a short life, serious consequences of failure, or high repair or replacement costs could offset a lower first cost. Similar savings in construction time are obtained using mechanically stabilized backfill systems, according to Leary and Klinedinst (1984).

10-7. Mechanisms and Behavior. The stability of mechanically stabilized backfill systems depends on transfer of stresses between the soil and reinforcements. Most reinforcements are inextensible in that they rupture at strains much less than those required to cause soil failure* (Mitchell and Villet 1986, Mitchell, Villet, and DiMillio 1984).

a. Mechanisms. The transfer of stress between soil and reinforcement is by friction and/or passive soil resistance when the reinforcement is loaded in tension. In many reinforcement systems both mechanisms are present, and the relative contribution of each is indeterminate.

(1) Friction. The load transferred by friction per unit area of reinforcement depends on the interface characteristics of the soil and reinforcement, and on the normal stress between them, which in turn depends on the stress-deformation behavior of the soil. This latter behavior is itself stress-dependent. Therefore, the effective friction coefficient cannot be estimated by analytical procedures. The results of experiments such as pullout tests, direct shear tests between soil and reinforcements, and instrumented model and full-scale tests, are often used to select friction coefficients. The coefficient of friction is defined as the average mobilized shear stress along the reinforcement divided by the normal stress from the overburden pressure. Empirical data from pullout tests on strip reinforcements show a decrease in this coefficient with depth regardless of the type of reinforcement (smooth or ribbed). This occurs because the effective normal stress is altered by the soil to reinforcement interaction. As shear strains are imposed on a dense granular soil, the soil tends to dilate. If the tendency to dilate is partially restrained by boundary conditions, local confining stresses will increase with the tendency to dilate decreasing as the confining stress increases. Hence, the influence of dilatancy on friction coefficients computed from pullout tests decreases with depth. Therefore, since the influence of dilatancy decreases with depth, the coefficient of friction also decreases with depth. Also, recent experience in construction with granular soils of low uniformity coefficients** (less than 4) indicates a relatively low friction coefficient ($\approx$1.0) for these types of granular soils.

(2) Passive Soil Resistance. Passive soil resistance to pullout of reinforcement develops against bearing surfaces which are normal to the direction of the pullout force. For grid reinforcing systems with the spacing of cross bars parallel to the wall equal to or greater than 6 inches, the major portion of the resistance (approximately 90 percent for bar mesh in a sandy gravel) is obtained by passive soil resistance or bearing capacity on the front face of elements oriented transverse to the pullout force direction.

(3) Strain Compatibility. Friction between the soil and a smooth reinforcement requires a small displacement of about 0.05 inch. Passive soil

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* Some geotextiles, which require large deformations to cause failure, are the exception.

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$$C_u = \frac{D_{60}}{D_{10}}$$

where C_u = coefficient of uniformity

D_{60} = grain diameter at 60 percent passing

D_{10} = grain diameter at 10 percent passing resistance against surfaces normal to displacement requires relative soil-to-reinforcement displacements as large as 4 inches for complete mobilization. However, a significant portion (greater than 50 percent) of the maximum value is mobilized at deflections of about 0.25 inch (Elias 1986). For bar mat grid reinforcement systems, the small beneficial effects of friction are neglected in view of possible strain incompatibility between frictional behavior and passive soil resistance.

b. Behavior. The distribution of lateral earth pressure within reinforced soil depends on the extensibility of the reinforcements, the construction methods used, and the type of reinforced structure. The active horizontal stress state is used for systems which are able to undergo relatively large lateral deformations, such as geotextiles. Higher lateral stresses, such as at-rest pressures, are associated with less extensible reinforcements, e.g., steel strips, bar meshes, welded wire mesh, and relatively low confining pressures, e.g., at shallow depths in the soil backfill where dilatancy is most effective. Under low confining stresses a reinforcement system may fail by pullout between the reinforcement and soil. Under high confining stresses the same system may fail by breakage of the reinforcements.

10-8. Materials. As previously mentioned, the three basic components of mechanically stabilized backfill systems are reinforcements, soil backfill, and facing elements (Mitchell and Villet 1986).

a. Reinforcement. The reinforcements may be characterized by the type of material (metallic and nonmetallic) and geometry (strips, grids, and sheets). Important material properties for reinforcements are strength and stability (low tendency to creep), high coefficient of friction with soil backfill, and durability. Depending on the electrochemical properties of the soil backfill and structure environment (marine or freshwater, presence of stray electrical currents in the ground, etc.) galvanized zinc-coated steel, resin-bonded epoxy-coated steel, or polymeric reinforcements are used. Polymeric reinforcements are not subject to corrosion but do exhibit creep characteristics (decrease in strength with time at constant load and soil temperature).

b. Soil Backfill. Most mechanically stabilized embankment systems have used cohesionless soil backfill. However, since grid reinforcements have a much greater pullout resistance than strip reinforcements, it is possible to construct mechanically stabilized embankment systems using silty or clayey material as backfill (Forsyth 1979 and Jackura 1984). The advantages of cohesionless soil backfill are that it is stable (will not creep), free-draining, not susceptible to frost, and relatively noncorrosive to reinforcement. The main disadvantage, where cohesionless soil has to be imported, is cost. The main advantage of cohesive soils is availability and hence lower cost. The disadvantages are long-term durability problems (corrosion and/or frost susceptibility) and distortion of the structure (due to creep of the soil backfill). When cohesionless soil backfill is readily available it should be used. When it is not readily available, the costs of importing cohesionless soil backfill should be weighed against the potentially poorer performance of using the lower-cost locally available cohesive soil backfill.

c. Facing Elements. Since facing elements play only a secondary structural role, a greater flexibility in choice of materials is available to meet aesthetic requirements than is the case for conventional retaining walls. A wide variety of materials, shapes, architectural finishes, and colors are available for facing elements. Selecting among these depends on the function of the structure, type of reinforcement, and aesthetics.

10-9. Design Considerations. The various engineering companies involved in a project provide site-specific designs for their proprietary system. Mechanically stabilized embankment systems must be designed for both external and internal stability. External stability is evaluated in a manner similar to a conventional gravity retaining wall. Internal stability depends on there being neither pullout nor breakage of the reinforcement (Mitchell and Villet 1986, Collin 1986).

a. External Stability. The mechanically stabilized backfill system must be stable against sliding along the base of the structure, overturning about the toe of the wall, bearing capacity failure of the foundation soil, overall slope stability, and differential settlement along the structure. For external stability calculations the mechanically stabilized backfill system is assumed to behave as a coherent block.

(1) Sliding Along the Base of the Structure. The mechanically stabilized backfill system must be stable against sliding due to the lateral pressure of the soil retained by the system. The minimum factor of safety against sliding should be 1.5. Sliding considerations may govern the design for high structures (greater than 30 feet) or structures with sloping backfills.

(2) Overturning About the Toe of the Wall. The mechanically stabilized backfill system must be stable against overturning about the toe of the wall. Since in reality the structure is flexible, it would probably never fail by overturning. One hundred percent of the base should always be in contact with the subgrade for all loading conditions (Elias 1986). Overturning considerations seldom govern the design of structures when the minimum reinforcement length is 70 percent of the wall height.

(3) Bearing Capacity Failure and Settlement. The mechanically stabilized backfill system must be stable against bearing capacity failure of the foundation soil. The minimum factor of safety against bearing capacity failure should be 2.0. This is lower than that used for conventional retaining walls (see Table 4-1) because of the flexibility of the mechanically stabilized backfill system and its ability to function satisfactorily after experiencing large differential settlements. If the foundation does not meet stability requirements, consideration should be given to ground improvement techniques such as stone columns, vibroflotation, and dynamic compaction to improve foundation stability. The maximum allowable differential settlement of mechanically stabilized backfill systems is limited by the longitudinal

deformability of the facing and the purpose of the structure. For precast concrete panels, without built-in vertical joints,* the limiting tolerable differential settlement is 1 foot per 100 feet of wall length.

(4) Overall Slope Stability. The mechanically stabilized backfill systems, retained soil, and foundation should be stable against slope failure. All potential slip surfaces should be investigated including those passing through the reinforcement and deep-seated sliding. The minimum factor of safety for slope stability should be 1.5.

b. Internal Stability. The mechanically stabilized backfill system must be stable against reinforcement pullout and reinforcement breaking.

(1) Reinforcement Pullout. In determining the reinforcement pullout capacity, the effective length of reinforcement behind the theoretical failure surface must be great enough to assure the transfer of stress from the reinforcement to the backfill soil without reinforcement pullout. The resistance to pullout may be frictional (strip reinforcement), passive (bar mesh reinforcement), or frictional-passive (Geogrid). Using data from laboratory pullout tests at a maximum of 0.75 inch of deformation, the structure should be designed with a minimum factor of safety against reinforcement pullout of 1.5 at each reinforcement level.

(2) Reinforcement Breaking. To assure a sufficient reinforcement breaking capacity, the effective cross-sectional area of the reinforcement (corrected for corrosion effects over the design life of the structure) must be great enough to allow for the transfer of stress from the reinforcement to the backfill soil without the reinforcement breaking. The design stress in the reinforcement should be taken as 55 percent of the yield stress (Elias 1986).

(3) Durability of Reinforcements. The durability of reinforcements, over the design life of the structure, is an important design consideration. Deterioration of polymeric reinforcements may occur due to abrasion during construction and decrease in strength with time at constant load and soil temperature. Corrosion of metallic reinforcement occurs due to exposure to air, water, and chemicals in the soil backfill. Galvanized zinc-coated steel (with a sacrificial thickness of steel added to give the required service life) is often used for reinforcing mild to moderately corrosive soil backfill with the following properties** (Frondistou-Yannas 1985).

Resistivity > 3,000 ohm-centimetres

pH 5-10

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* Hilfiker Reinforced Soil Embankment retaining walls have vertical joints built into the wall every 12.5 feet and can tolerate large differential settlements.

** Galvanized zinc-coated steel should not be used if the soil backfill contains illite clay because zinc is sensitive to illite.

Chlorides < 200 parts per million

Sulfates < 1,000 parts per million

For mild to moderately corrosive soil backfills the corrosion loss rates are:

Galvanization 6 μm/year for first 2 years

2.5 μm/year for subsequent years

Steel 9 μm/year after all zinc is lost

The use of aluminum and stainless steel reinforcement is not recommended as several failures have occurred using these materials (McGee 1985). For structures exposed to marine environments, stray electrical currents in the ground, or with soil backfill properties outside the electrochemical guidelines previously given, resin-bonded epoxy-coated metallic reinforcements or a conventional or precast concrete modular gravity wall should be used. A minimum epoxy coating thickness of 18 mils is necessary to survive transportation and installation, and to provide an acceptable level of design confidence. When epoxy-coated metallic reinforcement is used, the soil backfill should consist of rounded stone with a maximum particle size of 1 inch. For design purposes, the life of the epoxy coating should be assumed to be the same as a galvanized zinc coating of 2 oz/sq ft, or 30 years. A sacrificial thickness of steel should be added to provide the epoxy-coated reinforcement an adequate factor of safety at the design life of the structure (Frondistou-Yannas 1985, Jones 1985).

c. Drainage. Drainage measures must be considered for all mechanically stabilized backfill systems to prevent saturation of the soil backfill and to intercept surface flows containing aggressive elements such as deicing chemicals. When mechanically stabilized backfill systems support roadways which are chemically deiced in the winter, an impervious membrane should be placed between the pavement and the first row of metallic reinforcements to intercept any surface flows containing aggressive chemicals.

10-10. Construction Considerations. The construction of mechanically stabilized embankment systems does not require specialized contractors, skilled labor, or special equipment. Many of the components are prefabricated, providing ease of handling and forming and relatively quick construction. A small crane is used to handle and erect precast concrete facing panels. Front end loaders are used for loading dump trucks and spreading the soil backfill. Vibratory rollers are used to compact the soil backfill while small hand-operated compactors are used for compaction near the wall face. Preparation of the construction area consists of clearing vegetation, debris, and other deleterious material from the site. A concrete leveling pad, which is not a structural member, is constructed to facilitate the erection of the concrete panels. The first layer of soil backfill is placed and compacted and the reinforcement is laid on the surface of the compacted fill and covered with the next layer of fill. Construction equipment must not run on top of the reinforcement. Concrete panels are battered to the inside to compensate for the small outward movement to mobilize the resistance of the reinforcement. Filler material (cork, styrofoam, neoprene, etc.) is used between all horizontal joints to provide a uniform bearing surface between adjacent panels. A geotextile is placed over all joints on the fill side of the concrete panels to prevent fines from migrating from behind the wall (Mitchell and Villet 1986).

10-11. Instrumentation and Monitoring. The history of mechanically stabilized embankment systems is relatively short compared to the design life of the structure.* Therefore, continued accumulation of field data on a full-scale structure is necessary to verify design assumptions. Structures should be instrumented and monitored whenever atypical conditions exist such as cohesive soil backfill, epoxy-coated metallic reinforcement, or adverse groundwater conditions (outside the range specified in paragraph 10-9b(3)). Measurements should be made of horizontal and vertical displacements of the wall facing; soil pressures on the facing or on a vertical plane near the facing, the base of the wall, and perpendicular planes (horizontal and vertical) along the anticipated maximum tensile force line; tensile forces in the reinforcement including near the locus of maximum tensile force and near the wall facing; and pullout tests on short reinforcements. All mechanically stabilized embankment structures should be monitored once they are placed in operation to ensure stability. External stability of the mechanically stabilized embankment structure could be threatened by the same factors as a conventional retaining wall; e.g., clogging of the drainage system, erosion at the toe of the wall, etc. However, the mechanically stabilized embankment system could also fail due to changes in conditions which adversely influence the internal stability of the system. These include excavation within the soil backfill, changes in the groundwater conditions (outside the range specified in paragraph 10-9b(3)), and possible damage to the stabilizing ties because of vandalism to the exposed structure (Mitchell and Villet 1986, Al-Hussani and Perry 1978).

10-12. Maintenance and Repair. Since mechanically stabilized embankment systems are relatively new there is very limited field experience regarding maintenance and repair. Maintenance problems arising with facing elements could be repaired by conventional methods since the facing elements play a secondary role and resist only small horizontal earth pressures (Long et al. 1984). However, problems with the reinforcements, such as corrosion of metallic reinforcements, would be difficult to repair. One possible solution would be to use soil nailing to stabilize the structure (Jones 1985). Another method would be to place a stone buttress in front of the structure (Mitchell and Villet 1986).

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* Strip reinforcement was first utilized in U.S. construction in 1972, bar mesh reinforcement in 1975, and Geogrid reinforcement in 1984.

Section III. Precast Concrete Modular Systems

10-13. Background. Precast concrete modular systems consist of interlocking soil-filled reinforced concrete modules which form a gravity retaining wall. They can be erected rapidly and are cost-competitive with mechanically stabilized backfill systems.*

10-14. Basic Components. The basic components of precast concrete modular systems are interlocking precast reinforced concrete modular elements filled with soil and resting on natural soil or a concrete foundation (see Figures 10-5 to 10-8). Some systems have resets or an open-face structure at the wall face (see Figures 10-7 and 10-8) with evergreen vegetation to reduce noise levels and eliminate the problem of graffiti.

10-15. Advantages and Disadvantages. The advantages and disadvantages of precast concrete modular systems are listed below.

a. Advantages.

(1) Modular systems are economical when compared to conventional retaining walls in cut situations, particularly where the retaining wall has a total surface area greater than 500 sq ft and average wall heights greater than 8 feet.

(2) Assembly of the wall components requires no fasteners and the modules may be reused easily and economically.

(3) The precast concrete modular retaining wall does not utilize reinforcing elements and therefore is not subject to corrosion damage.

(4) Excavation behind the precast concrete modular retaining wall does not adversely influence the stability of the system as might occur for the mechanically stabilized wall.

b. Disadvantage. The precast concrete modular retaining wall could sustain cracking of interior connecting members due to relatively small (0.5 foot per 100 feet of wall length) longitudinal differential settlement.

10-16. Design Considerations. Various engineering companies involved will provide site-specific plans and limited designs for their proprietary system. Stability is evaluated in a manner similar to a conventional gravity retaining wall. For stability calculations the interlocking precast concrete modular system is assumed to behave as a coherent block. The system must be stable

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* For certain applications, such as where large differential vertical settlements are anticipated, consideration should be given to steel-bin type retaining walls which are generally more expensive than mechanically stabilized backfill or precast concrete modular systems but less expensive than conventional retaining walls.

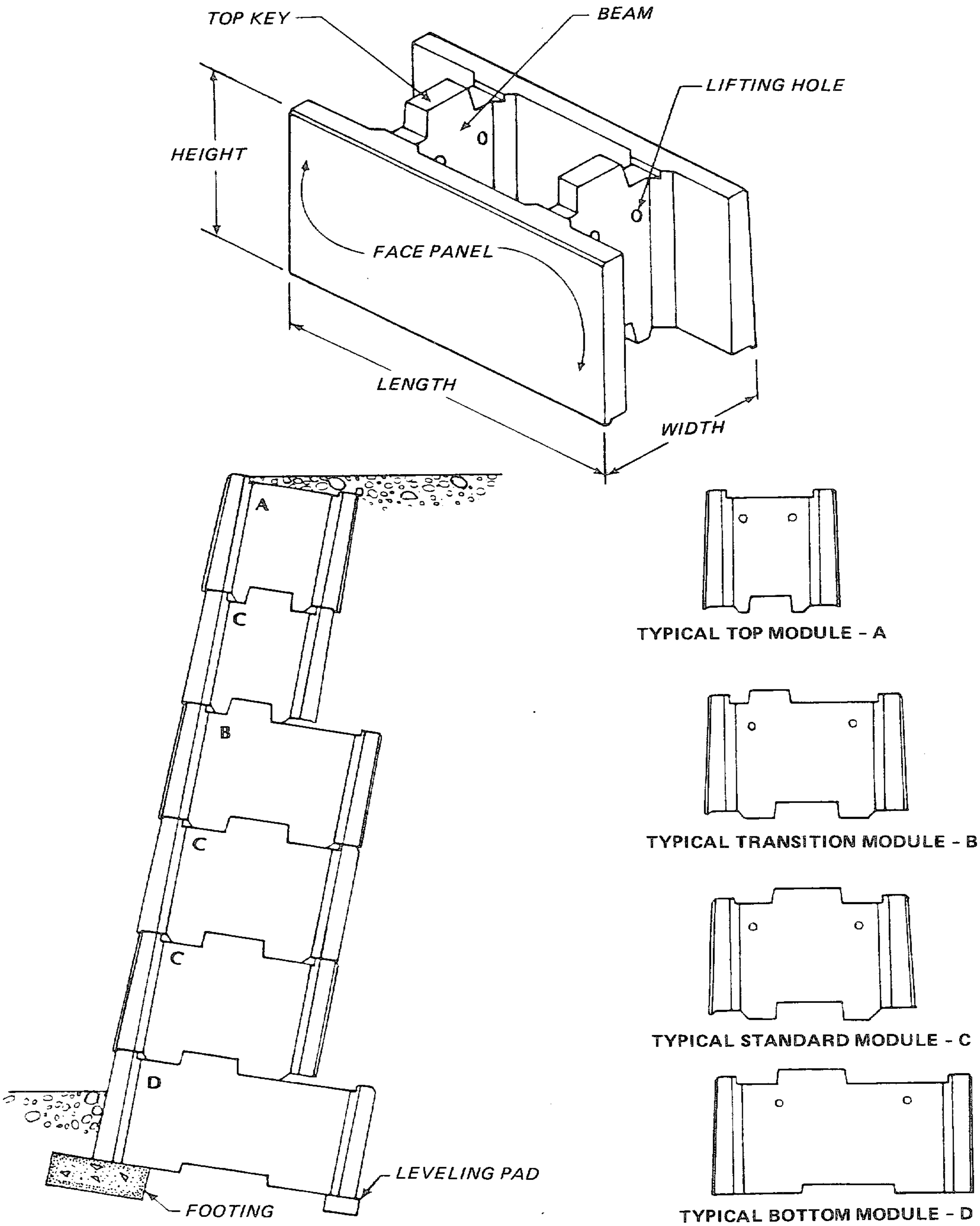

Figure 10-5. Schematic diagram of Doublewal retaining wall (after Doublewal Corporation 1984)

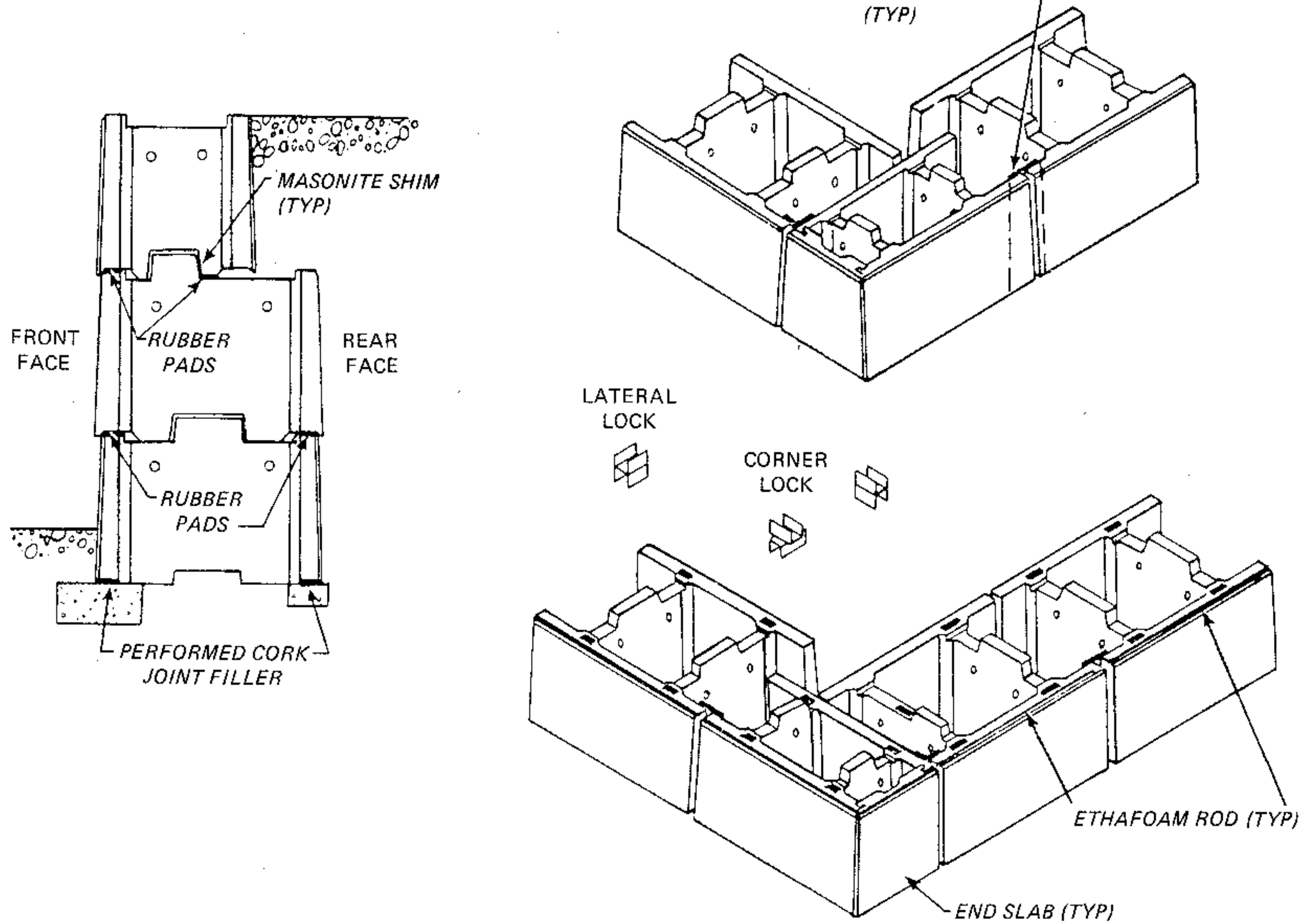

Figure 10-6. Materials used to construct Doublewal retaining wall
(after Doublewal Corporation 1984)

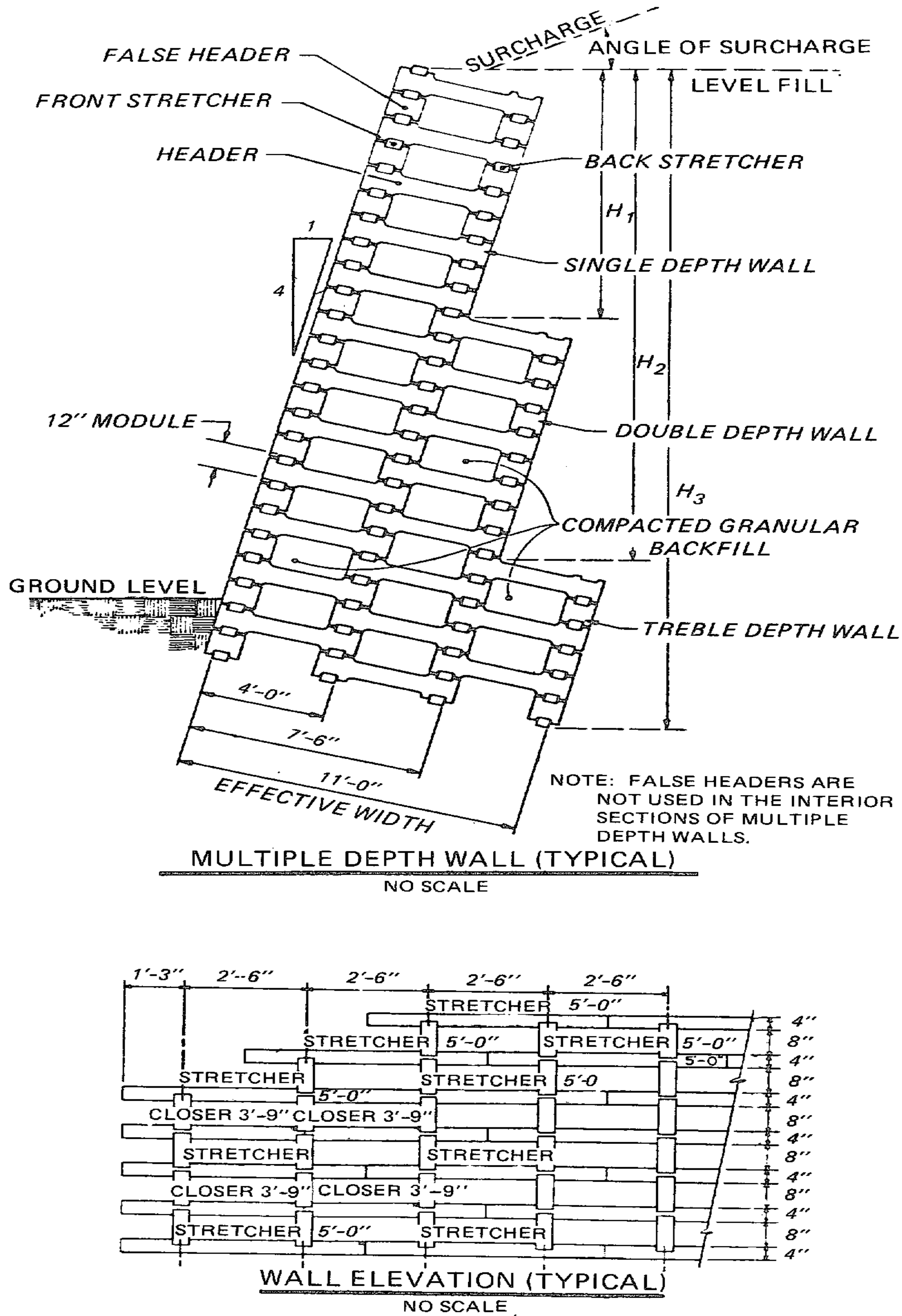

Figure 10-7. Schematic diagram of Criblock retaining wall (after Criblock Retaining Walls of America)

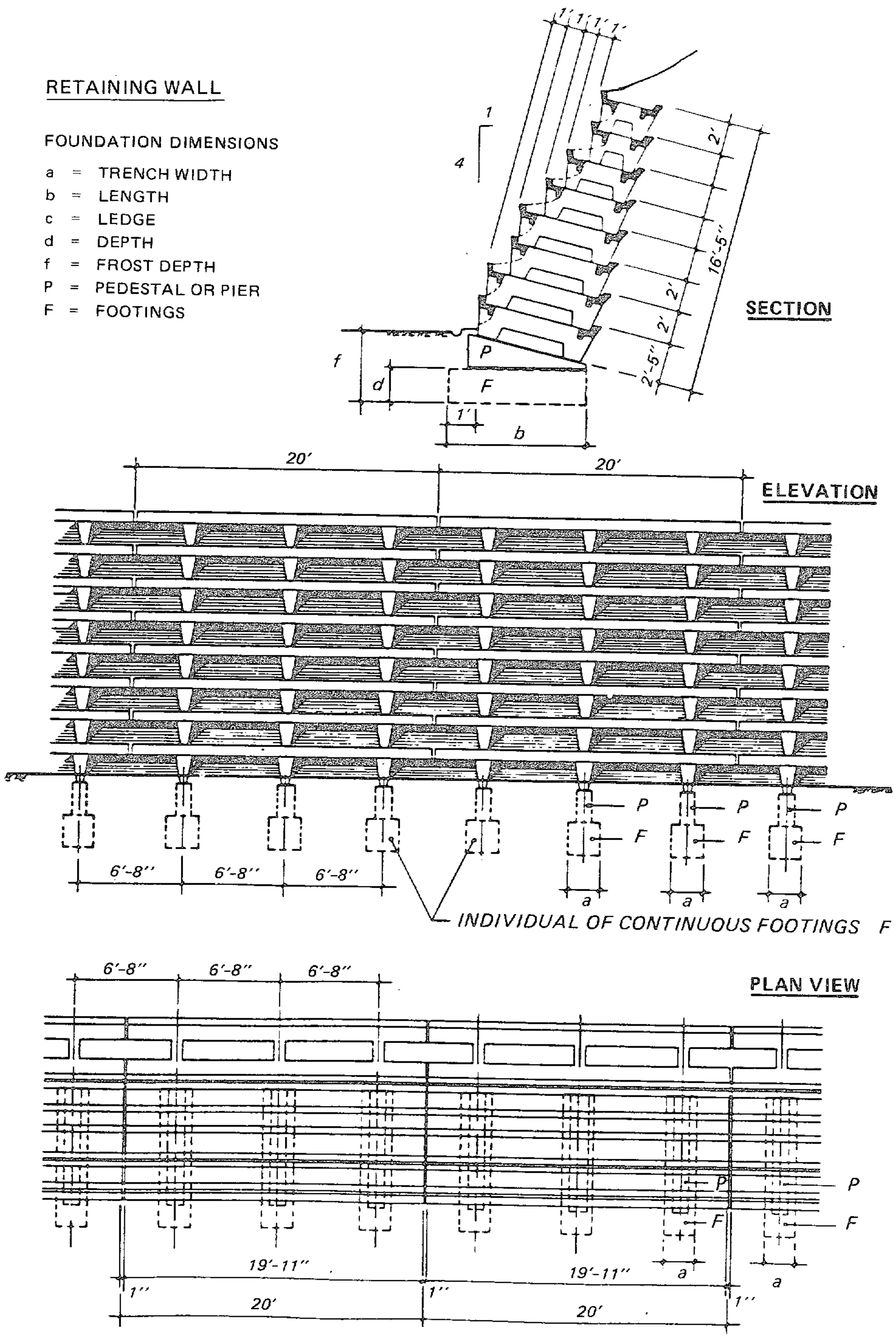

Figure 10-8. Schematic diagram of Evergreen retaining wall (after Evergreen Systems, Inc.)

against sliding along the base of the structure, overturning about the toe of the wall, bearing capacity failure of the foundation soil, differential settlement, and overall slope stability.

a. Sliding Along The Base Of The Structure. The precast concrete modular system must be stable against sliding due to the lateral pressure of the soil retained by the system. The minimum factor of safety against sliding should be 1.5.

b. Overturning About The Toe Of The Wall. The precast concrete modular system must be stable against overturning about the toe of the wall. Since the concrete modular units are not tied together vertically, the stability against overturning must be checked at each concrete module level for a given width. One hundred percent of the base should always be in contact with the subgrade for all loading conditions (Elias 1986). Normally overturning (not sliding) criteria govern the design.

c. Bearing Capacity Failure and Settlement. The precast concrete modular system must be stable against bearing capacity failure of the foundation soil. The minimum factor of safety against bearing capacity failure should be 3.0 (Elias 1986). If the foundation does not meet stability requirements, consideration should be given to use of a mechanically stabilized backfill system or ground improvement techniques such as stone columns, vibroflotation, and dynamic compaction to improve foundation stability. As previously stated, the precast concrete modular retaining wall could sustain cracking of interior connecting members due to relatively small (0.5 foot per 100 feet of wall length) longitudinal differential settlement. Precast concrete modular retaining walls are also susceptible to damage from differential settlement perpendicular to the wall face, particularly on high walls where the bottom wall units may be as wide as 20 feet.

d. Overall Slope Stability. The precast concrete modular system, retained soil, and foundation should be stable against slope failure. All potential slip surfaces should be investigated including deep-seated sliding. The minimum factor of safety for slope stability should be 1.5.

e. Drainage. Drainage measures must be considered for all precast concrete modular systems to prevent saturation of the soil backfill. Also, for closed-face modular systems (see Figure 10-5), a geotextile is placed over all joints on the back side of the front face of the wall to prevent fines from migrating from behind the wall.

10-17. Construction Considerations. The construction of precast concrete modular systems does not require specialized contractors, skilled labor, or special equipment. The components are prefabricated providing ease of handling and forming and relatively quick construction. Soil backfill within the precast modular units should receive adequate compaction to minimize post-construction settlements.

10-18. Instrumentation and Monitoring. The history of precast concrete modular systems is relatively short compared to the design life of the structure.* Therefore, continued accumulation of field data is necessary to verify design assumptions. Structures should be instrumented and monitored whenever atypical conditions exist such as anticipated large differential vertical settlement. Measurements should be made of horizontal and vertical displacements of the front face of the wall and soil pressures on the rear face of the wall. All precast concrete modular structures should be monitored once they are placed in operation to ensure stability. Stability of the precast concrete modular structure could be threatened by the same factors as a conventional retaining wall; e.g., clogging of the drainage system, erosion at the toe of the wall, etc. Precast concrete modular structures should also be monitored for possible damage from differential settlements.

10-19. Maintenance and Repair. Since precast concrete modular structures are relatively new, there is very limited field experience regarding maintenance and repair. Possible methods of repair to a section of the structure which has sustained damage from differential settlement include replacing the section with a wall more tolerant to differential settlement, such as a mechanically stabilized embankment system with vertical joints (see Figure 10-2) or a steel-bin type wall, or placing a stone buttress in front of the structure.

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* Criblock was first used in US construction in 1978, Doublewal in 1979, and Evergreen in 1986.